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Lepton Polarization in the Decays $B \to X_s\,\mu^+\mu^-$ and $B \to X_s\,\tau^+\tau^-$

F. Krüger* and L. M. Sehgal†
Institut für Theoretische Physik (E), RWTH Aachen
D-52074 Aachen, Germany

ABSTRACT

The effective Hamiltonian for the decay $b \to s\,l^+l^-$ predicts a characteristic polarization for the final state lepton, which can serve as an important test of the underlying theory. The lepton polarization has, in addition to a longitudinal component P_{L}, two orthogonal components P_{T} and P_{N}, lying in and perpendicular to the decay plane which are proportional to m_l/m_b, and therefore significant for the $\tau^+\tau^-$ channel. The normal polarization component P_{N} is a T-odd effect connected with the nonhermiticity of the effective Hamiltonian, arising mainly from $c\bar{c}$ intermediate states. We calculate all three polarization components for the decay $B \to X_s\,\tau^+\tau^-$ as a function of the lepton pair mass, and find average values $\langle P_{\mathrm{L}}\rangle_\tau = -0.37$, $\langle P_{\mathrm{T}}\rangle_\tau = -0.63$, $\langle P_{\mathrm{N}}\rangle_\tau = 0.03$. By comparison, the μ^- polarization is $\langle P_{\mathrm{L}}\rangle_\mu = -0.77$, $\langle P_{\mathrm{T}}\rangle_\mu = \langle P_{\mathrm{N}}\rangle_\mu \approx 0$.

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*Electronic address: krueger@physik.rwth-aachen.de

†Electronic address: sehgal@physik.rwth-aachen.de

I. INTRODUCTION

The decay $B \to X_s\, l^+l^-$ has received considerable attention as a potential testing ground for the effective Hamiltonian describing flavour-changing neutral current processes in B decay (see e.g. Ref. [1]). This Hamiltonian contains the one-loop effects of the electroweak interaction, which are sensitive to the top-quark mass [2–4]. In addition, there are important QCD corrections [5–8], which have recently been calculated in next-to-leading order [4, 9]. The inclusive distributions have been studied in [5, 10, 11], while the exclusive channels $B \to K l^+l^-$ and $B \to K^* l^+l^-$ have been analysed in [3, 12]. Recently, attention has been drawn to the fact that the longitudinal polarization of the lepton, $P_{\rm L}$, in $B \to X_s\, l^+l^-$ is an important observable, that may be especially accessible in the mode $B \to X_s\, \tau^+\tau^-$ [13]. The purpose of this paper is to show that complementary information is contained in the two orthogonal components of polarization ($P_{\rm T}$, the component in the decay plane, and $P_{\rm N}$, the component normal to the decay plane), both of which are proportional to m_l/m_b, and therefore significant for the $\tau^+\tau^-$ channel. The normal component $P_{\rm N}$, in particular, is a novel feature, since it is a T-odd observable, that comes about because of the nonhermiticity of the effective Hamiltonian, associated with real $c\bar{c}$ intermediate states.

II. SHORT-DISTANCE CONTRIBUTIONS

The effective short-distance Hamiltonian for $b \to s\, l^+l^-$ [4, 5, 7, 8] leads to the QCD-corrected matrix element

$$\begin{aligned} \mathcal{M} \;=\; & \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \, \frac{\alpha}{4\pi} \bigg\{ c_9^{\rm eff}\, (\bar{s}\gamma_\mu P_L b)\, \bar{l}\gamma^\mu l + c_{10}\, (\bar{s}\gamma_\mu P_L b)\, \bar{l}\gamma^\mu\gamma^5 l \\ & - 2\, c_7^{\rm eff}\, \bar{s}\; i\sigma_{\mu\nu} \frac{q^\nu}{q^2}\, (m_b P_R + m_s P_L)\, b\, \bar{l}\gamma^\mu l \bigg\} , \end{aligned} \tag{2.1}$$

where $P_{L,R} = \frac{1}{2}(1 \mp \gamma_5)$, and the analytic expressions for the Wilson coefficients are given in Ref. [4]. We use in our analysis the parameters given in the Appendix and

obtain in leading logarithmic approximation

$$c_7^{\text{eff}} = -0.315, \quad c_{10} = -4.642 \ , \tag{2.2}$$

and in next-to-leading order

$$\begin{aligned} c_9^{\text{eff}} &= c_9 \tilde{\eta}(\hat{s}) + g(\hat{m}_c, \hat{s}) \left(3c_1 + c_2 + 3c_3 + c_4 + 3c_5 + c_6\right) - \frac{1}{2} g(\hat{m}_s, \hat{s}) \left(c_3 + 3c_4\right) \\ &\quad - \frac{1}{2} g(\hat{m}_b, \hat{s}) \left(4c_3 + 4c_4 + 3c_5 + c_6\right) + \frac{2}{9} \left(3c_3 + c_4 + 3c_5 + c_6\right) \ , \end{aligned} \tag{2.3}$$

with

$$\begin{aligned} (3c_1 + c_2 + 3c_3 + c_4 + 3c_5 + c_6) &= 0.359 \ , \\ (4c_3 + 4c_4 + 3c_5 + c_6) &= -6.749 \times 10^{-2} \ , \\ (3c_3 + c_4 + 3c_5 + c_6) &= -1.558 \times 10^{-3} \ , \\ (c_3 + 3c_4) &= -6.594 \times 10^{-2} \ , \\ c_9 \tilde{\eta}(\hat{s}) &= 4.227 + 0.124 \, \omega(\hat{s}) \ , \end{aligned} \tag{2.4}$$

where we have introduced the notation $\hat{s} = q^2/m_b^2$, $\hat{m}_i = m_i/m_b$. The function $\omega(\hat{s})$ represents the one-gluon correction[1] to the matrix element of the operator $\mathcal{O}_9$, while $g(\hat{m}_i, \hat{s})$ arises from the one-loop contributions of the four-quark operators $\mathcal{O}_1$ and $\mathcal{O}_2$, and is given by

$$\begin{aligned} g(\hat{m}_i, \hat{s}) &= -\frac{8}{9} \ln(\hat{m}_i) + \frac{8}{27} + \frac{4}{9} y_i - \frac{2}{9} (2 + y_i) \sqrt{|1 - y_i|} \\ &\quad \times \left\{ \Theta(1 - y_i) (\ln \left(\frac{1 + \sqrt{1 - y_i}}{1 - \sqrt{1 - y_i}} \right) - i\pi) + \Theta(y_i - 1) 2 \arctan \frac{1}{\sqrt{y_i - 1}} \right\} \ , \end{aligned} \tag{2.5}$$

where $y_i \equiv 4\hat{m}_i^2/\hat{s}$.

[1] See Refs. [4] and [9]. Here we neglect corrections due to a nonzero lepton mass. This will be discussed in a further publication.

III. LONG-DISTANCE CONTRIBUTIONS

In addition to the short-distance interaction defined by Eqs. (2.1)–(2.4) it is possible to take into account long-distance effects, associated with real $c\bar{c}$ resonances in the intermediate states, i.e. with the reaction chain $B \to X_s + V(c\bar{c}) \to X_s\, l^+l^-$. This can be accomplished in an approximate manner through the substitution [14]

$$g(\hat{m}_c, \hat{s}) \longrightarrow g(\hat{m}_c, \hat{s}) - \frac{3\pi}{\alpha^2} \sum_{V=J/\psi,\psi',\ldots} \frac{\hat{m}_V \mathrm{Br}\,(V \to l^+l^-)\hat{\Gamma}^V_{\mathrm{total}}}{\hat{s} - \hat{m}_V^2 + i\hat{m}_V\hat{\Gamma}^V_{\mathrm{total}}}\,, \tag{3.1}$$

where the properties of the vector mesons are summarized in Table I. There are six

TABLE I: Charmonium ($c\bar{c}$) masses and widths [15].

Meson	Mass (GeV)	$\mathrm{Br}\,(V \to l^+l^-)$	Γ_{total} (MeV)
$J/\Psi(1\mathrm{S})$	3.097	6.0×10^{-2}	0.088
$\Psi(2\mathrm{S})$	3.686	8.3×10^{-3}	0.277
$\Psi(3770)$	3.770	1.1×10^{-5}	23.6
$\Psi(4040)$	4.040	1.4×10^{-5}	52
$\Psi(4160)$	4.159	1.0×10^{-5}	78
$\Psi(4415)$	4.415	1.1×10^{-5}	43

known resonances in the $c\bar{c}$ system that can contribute to the decay modes $B \to X_s\, e^+e^-$ and $B \to X_s\, \mu^+\mu^-$. Of these, all except the lowest $J/\psi(3097)$ contribute to the channel $B \to X_s\, \tau^+\tau^-$, for which the invariant mass of the lepton pair is $s > 4m_\tau^2$.[2]

[2] As noted by several authors [10,16], the ansatz (3.1) for the resonance contribution implies an inclusive direct J/ψ production rate $\mathrm{Br}\,(B \to J/\psi X_s) = 0.15\%$ that is ~ 5 times smaller than the measured J/ψ rate [17]. This is usually amended by the introduction of a phenomenological factor $\kappa_V \approx 2$ multiplying the Breit-Wigner function in (3.1). In the present paper, the only observable that is significantly affected by this change is the polarization component P_{N}, where we will show the results for both $\kappa_V = 1$ and $\kappa_V = 2.35$.

Alternatively, we can express $g(\hat{m}_i, \hat{s})$, Eq. (2.5), through the renormalized vacuum polarization $\Pi^{\gamma}_{\rm had}(\hat{s})$, which is related to the experimentally measurable quantity $R_{\rm had}(\hat{s}) \equiv \sigma_{\rm tot}(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ via a dispersion relation [18], i.e.

$$\mathrm{Re}\, \Pi^{\gamma}_{\rm had}(\hat{s}) = \frac{\alpha \hat{s}}{3\pi}\; P \int\limits_{4\hat{m}_\pi^2}^{\infty} \frac{R_{\rm had}(\hat{s}')}{\hat{s}'(\hat{s}'-\hat{s})} d\hat{s}', \quad \text{and} \quad \mathrm{Im}\, \Pi^{\gamma}_{\rm had}(\hat{s}) = \frac{\alpha}{3} R_{\rm had}(\hat{s}) \;, \tag{3.2}$$

where P denotes the principal value. Using these relations, one finds for the $c\bar{c}$ contribution

$$\mathrm{Im}\, g(\hat{m}_c, \hat{s}) = \frac{\pi}{3} R^{c\bar{c}}_{\rm had}(\hat{s}) \;, \tag{3.3}$$

and

$$\mathrm{Re}\, g(\hat{m}_c, \hat{s}) = -\frac{8}{9} \ln \hat{m}_c - \frac{4}{9} + \frac{\hat{s}}{3}\; P \int\limits_{4\hat{m}_D^2}^{\infty} \frac{R^{c\bar{c}}_{\rm had}(\hat{s}')}{\hat{s}'(\hat{s}'-\hat{s})} d\hat{s}' \;. \tag{3.4}$$

The cross-section ratio $R^{c\bar{c}}_{\rm had}$ may be written as

$$R^{c\bar{c}}_{\rm had}(\hat{s}) = R^{c\bar{c}}_{\rm cont}(\hat{s}) + R^{c\bar{c}}_{\rm res}(\hat{s}) \;, \tag{3.5}$$

where $R^{c\bar{c}}_{\rm cont}$ and $R^{c\bar{c}}_{\rm res}$ denote the contributions from the continuum and the narrow resonances, respectively. The latter is given by the Breit-Wigner formula

$$R^{c\bar{c}}_{\rm res}(\hat{s}) = \sum_{V = J/\psi, \psi', \ldots} \frac{9\hat{s}}{\alpha^2}\; \frac{\mathrm{Br}\,(V \to l^+ l^-) \hat{\Gamma}^V_{\rm total} \hat{\Gamma}^V_{\rm had}}{(\hat{s} - \hat{m}_V^2)^2 + \hat{m}_V^2 \hat{\Gamma}^{V\,2}_{\rm total}} \;, \tag{3.6}$$

whereas $R^{c\bar{c}}_{\rm cont}$ can be determined using the experimental data. We use the parametrization of $R^{c\bar{c}}_{\rm cont}$ given in [19] (see Appendix). In Fig. 1, the imaginary part of $g(\hat{m}_c, \hat{s})$, Eq. (2.5), is plotted and compared with $\mathrm{Im}\, g(\hat{m}_c, \hat{s})$, Eq. (3.3). Our numerical results are based on Eqs. (3.3) and (3.4), with the parameter κ_V chosen equal to 2.35.

IV. RATE AND FORWARD-BACKWARD ASYMMETRY

Neglecting nonperturbative corrections [20], the decay width as a function of the invariant mass of the lepton pair ($q^2 \equiv m^2_{l^+l^-}$) is given by

$$\frac{d\Gamma}{d\hat{s}} = \frac{G_F^2 m_b^5}{192\pi^3} \frac{\alpha^2}{4\pi^2} |V_{tb}V_{ts}^*|^2 \lambda^{1/2}(1,\hat{s},\hat{m}_s^2) \sqrt{1-\frac{4\hat{m}_l^2}{\hat{s}}}\, \Delta \ , \tag{4.1}$$

where the factors λ and Δ are defined by

$$\lambda(a,b,c) = a^2+b^2+c^2-2(ab+bc+ac) \ , \tag{4.2}$$

and

$$\begin{aligned} \Delta \ = \ & \left\{ \left(12\,\mathrm{Re}\,(c_7^{\mathrm{eff}}c_9^{\mathrm{eff}})F_1(\hat{s},\hat{m}_s^2) + \frac{4}{\hat{s}}|c_7^{\mathrm{eff}}|^2 F_2(\hat{s},\hat{m}_s^2)\right)\left(1+\frac{2\hat{m}_l^2}{\hat{s}}\right) \right. \\ & \left. + \left(|c_9^{\mathrm{eff}}|^2+|c_{10}|^2\right) F_3(\hat{s},\hat{m}_s^2,\hat{m}_l^2) + 6\,\hat{m}_l^2\left(|c_9^{\mathrm{eff}}|^2-|c_{10}|^2\right) F_4(\hat{s},\hat{m}_s^2) \right\} \ , \end{aligned} \tag{4.3}$$

with

$$F_1(\hat{s},\hat{m}_s^2) = (1-\hat{m}_s^2)^2 - \hat{s}(1+\hat{m}_s^2) \ , \tag{4.4}$$

$$F_2(\hat{s},\hat{m}_s^2) = 2(1+\hat{m}_s^2)(1-\hat{m}_s^2)^2 - \hat{s}(1+14\hat{m}_s^2+\hat{m}_s^4) - \hat{s}^2(1+\hat{m}_s^2) \ , \tag{4.5}$$

$$F_3(\hat{s},\hat{m}_s^2,\hat{m}_l^2) = (1-\hat{m}_s^2)^2 + \hat{s}(1+\hat{m}_s^2) - 2\hat{s}^2 + \lambda(1,\hat{s},\hat{m}_s^2)\frac{2\hat{m}_l^2}{\hat{s}} \ , \tag{4.6}$$

$$F_4(\hat{s},\hat{m}_s^2) = 1-\hat{s}+\hat{m}_s^2 \ . \tag{4.7}$$

If the lepton mass m_l is neglected, we recover the results of Ali *et al.* [10,11]. If the strange-quark mass m_s is also neglected, we obtain the results of Grinstein *et al.* [5] and Buras and Münz [4]. Finally, for $m_l \neq 0$ but $m_s = 0$, we reproduce the result given by Hewett [13].

To complete the correspondence with previous results, we give here the forward-backward asymmetry of the lepton l^- in the l^+l^- centre-of-mass system:

$$A_{\mathrm{FB}}(\hat{s}) = -3\,\lambda^{1/2}(1,\hat{s},\hat{m}_s^2)\sqrt{1-\frac{4\hat{m}_l^2}{\hat{s}}}\ \frac{c_{10}\left[\hat{s}\,\mathrm{Re}\,c_9^{\mathrm{eff}} + 2\,c_7^{\mathrm{eff}}(1+\hat{m}_s^2)\right]}{\Delta} \ . \tag{4.8}$$

This agrees with Ref. [10] when m_l is neglected.

V. LEPTON-POLARIZATION

We now proceed to a discussion of the inclusive lepton polarization. We define three orthogonal unit vectors

$$\begin{aligned} \mathbf{e}_\mathrm{L} &= \frac{\mathbf{p}_-}{|\mathbf{p}_-|} \ , \\ \mathbf{e}_\mathrm{N} &= (\mathbf{p}_s \times \mathbf{p}_-)/|\mathbf{p}_s \times \mathbf{p}_-| \ , \\ \mathbf{e}_\mathrm{T} &= \mathbf{e}_\mathrm{N} \times \mathbf{e}_\mathrm{L} \ , \end{aligned} \tag{5.1}$$

where $\mathbf{p}_-$ and $\mathbf{p}_s$ are three-momenta of the l^- and the s quark, respectively, in the c.m. frame of the l^+l^- system. The differential decay rate of $B \to X_s\, l^+l^-$ for any given spin direction $\mathbf{n}$ of the lepton l^-, where $\mathbf{n}$ is a unit vector in the l^- rest frame, may then be written as

$$\frac{d\Gamma(\mathbf{n})}{d\hat{s}} = \frac{1}{2}\left(\frac{d\Gamma}{d\hat{s}}\right)_\mathrm{unpol}\left[1 + (P_\mathrm{L}\mathbf{e}_\mathrm{L} + P_\mathrm{T}\mathbf{e}_\mathrm{T} + P_\mathrm{N}\mathbf{e}_\mathrm{N})\cdot\mathbf{n}\right] , \tag{5.2}$$

where P_L, P_T, P_N are functions of $\hat{s}$, which give the longitudinal, transverse and normal components of polarization. The polarization component P_i $(i = \mathrm{L,T,N})$ is obtained by evaluating

$$P_i(\hat{s}) = \frac{d\Gamma(\mathbf{n}=\mathbf{e}_i)/d\hat{s} - d\Gamma(\mathbf{n}=-\mathbf{e}_i)/d\hat{s}}{d\Gamma(\mathbf{n}=\mathbf{e}_i)/d\hat{s} + d\Gamma(\mathbf{n}=-\mathbf{e}_i)/d\hat{s}} \ . \tag{5.3}$$

Our results for the polarization components P_L, P_T and P_N are as follows

$$\begin{aligned} P_\mathrm{L}(\hat{s}) &= \sqrt{1 - \frac{4\hat{m}_l^2}{\hat{s}}}\Big[12\, c_7^\mathrm{eff} c_{10}\Big((1-\hat{m}_s^2)^2 - \hat{s}(1+\hat{m}_s^2)\Big) \\ &\quad + 2\,\mathrm{Re}\,(c_9^\mathrm{eff} c_{10})\Big((1-\hat{m}_s^2)^2 + \hat{s}(1+\hat{m}_s^2) - 2\hat{s}^2\Big)\Big]\Big/\Delta \ , \end{aligned} \tag{5.4}$$

$$P_\mathrm{T}(\hat{s}) = \frac{3\pi\hat{m}_l}{2\sqrt{\hat{s}}}\lambda^{1/2}(1,\hat{s},\hat{m}_s^2)\Big[c_7^\mathrm{eff} c_{10}(1-\hat{m}_s^2) - 4\,\mathrm{Re}\,(c_7^\mathrm{eff} c_9^\mathrm{eff})(1+\hat{m}_s^2)$$

$$-\frac{4}{\hat{s}}\,|c_7^{\rm eff}|^2(1-\hat{m}_s^2)^2+{\rm Re}\,(c_9^{\rm eff}c_{10})(1-\hat{m}_s^2)-|c_9^{\rm eff}|^2\hat{s}\Big]\,/\Delta\;, \tag{5.5}$$

$$P_{\rm N}(\hat{s}) \;=\; \frac{3\pi\hat{m}_l}{2\Delta}{\rm Im}\,(c_9^{{\rm eff}*}c_{10})\sqrt{\hat{s}}\,\lambda^{1/2}(1,\hat{s},\hat{m}_s^2)\sqrt{1-\frac{4\hat{m}_l^2}{\hat{s}}}\;. \tag{5.6}$$

The expression for $P_{\rm L}$ agrees with that obtained by Hewett [13], when we set $\hat{m}_s = 0$ in Eq. (5.4).

It should be noted that the polarization components $P_{\rm L}$, $P_{\rm T}$ and $P_{\rm N}$ involve different quadratic functions of the effective couplings $c_7^{\rm eff}$, $c_9^{\rm eff}$ and c_{10}, and therefore contain independent information. The component $P_{\rm N}$ is proportional to the absorptive part of the effective coupling $c_9^{\rm eff}$, which is dominated by the charm-quark contribution (cf. Eq. (2.3)). It is obvious that the polarization is affected by any alteration in the relative magnitude and sign of $c_7^{\rm eff}$, $c_9^{\rm eff}$ and c_{10}, and thus can serve as a probe of possible new interactions transcending the standard model.

The polarization components $P_{\rm L}$, $P_{\rm T}$ and $P_{\rm N}$ are plotted in Figs. 2–5. In the case of the $\mu^+\mu^-$ channel, the only significant component is $P_{\rm L}$, which has a large negative value over most of the $\hat{s}$ domain, with an average value $\langle P_{\rm L}\rangle_\mu = -0.77$. By contrast, all three components are sizeable in the $\tau^+\tau^-$ channel, with average values $\langle P_{\rm L}\rangle_\tau = -0.37$, $\langle P_{\rm T}\rangle_\tau = -0.63$, $\langle P_{\rm N}\rangle_\tau = 0.03\,(0.02)$ for $\kappa_V = 2.35\,(1)$. Notice that the T-odd component $P_{\rm N}$, though small, is considerably larger than the corresponding normal polarization of leptons in $K_L \to \pi^+\mu^-\bar{\nu}$ or $K^+ \to \pi^+\mu^+\mu^-$, which requires a final state Coulomb interaction of the lepton with the other charged particles, and is typically of order $\alpha(m_\mu/m_K) \sim 10^{-3}$ [21].

The inclusive branching ratios are predicted to be ${\rm Br}\,(B \to X_s\,\mu^+\mu^-) = 6.7 \times 10^{-6}$, ${\rm Br}\,(B \to X_s\,\tau^+\tau^-) = 2.5 \times 10^{-7}$. The lower rate of the $\tau^+\tau^-$ channel may be offset by the fact that the decay of the τ acts as a self-analyser of the τ polarization. Assuming (as in Ref. [13]) a total of 5×10^8 $B\bar{B}$ decays, one can expect to observe $\sim$ 100 identified $B \to X_s\,\tau^+\tau^-$ events, permitting a test of the predicted polarizations $\langle P_{\rm L}\rangle = -0.37$, and $\langle P_{\rm T}\rangle = -0.63$ with good accuracy. We shall discuss in a more

detailed paper the dependence of the lepton polarization on the production angle θ, the spin correlation of the l^+l^- pair, the influence of nonperturbative effects (quark-binding corrections), as well as lepton-spin effects in exclusive channels.

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APPENDIX: INPUT PARAMETERS

$$\begin{aligned}
&m_b = 4.8 \text{ GeV},\ m_c = 1.4 \text{ GeV},\ m_s = 0.2 \text{ GeV},\ m_t = 176 \text{ GeV}\ , \\
&m_\mu = 0.106 \text{ GeV},\ m_\tau = 1.777 \text{ GeV},\ M_W = 80.2 \text{ GeV},\ \mu = m_b\ , \\
&V_{tb} = 1,\ V_{ts}^* = -V_{cb},\ \mathrm{Br}\,(B \to X_c\, l\bar{\nu}_l) = 10.4\%\ , \\
&\Lambda_{\rm QCD} = 225 \text{ MeV},\ \alpha = 1/129,\ \sin^2\theta_{\rm W} = 0.23\ .^3
\end{aligned} \tag{A1}$$

$$R_{\rm cont}^{c\bar{c}}(\hat{s}) = \begin{cases} 0 \quad \text{for} \quad 0 \le \hat{s} \le 0.60\ , \\ -6.80 + 11.33\hat{s} \quad \text{for} \quad 0.60 \le \hat{s} \le 0.69\ , \\ 1.02 \quad \text{for} \quad 0.69 \le \hat{s} \le 1\ . \end{cases} \tag{A2}$$

[3] We use $\alpha_s(\mu)$ that is given by the formula (4.12) of Ref. [4].

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FIGURE CAPTIONS

Figure 1 The imaginary part $\mathrm{Im}\, g(\hat{m}_c, \hat{s})$ as a function of the invariant mass of the lepton pair. The dashed line represents the theoretical result, neglecting long-distance effects, and the solid curve shows the imaginary part using $R_{\mathrm{had}}^{c\bar{c}}(\hat{s})$, as described in the text.

Figure 2 The longitudinal polarization P_{L} for the μ^- including the $c\bar{c}$ resonances ($\kappa_V = 2.35$).

Figure 3 The longitudinal polarization P_{L} for the tau lepton including $c\bar{c}$ resonances.

Figure 4 The transverse polarization P_{T} (in the decay plane) of the τ^- for $\hat{s} \geq 4\hat{m}_\tau^2$.

Figure 5 The normal polarization P_{N}, i.e. normal to the decay plane, in the $\tau^+\tau^-$ channel including $c\bar{c}$ intermediate states. The solid line corresponds to $\kappa_V = 2.35$, the dashed one is $\kappa_V = 1$.

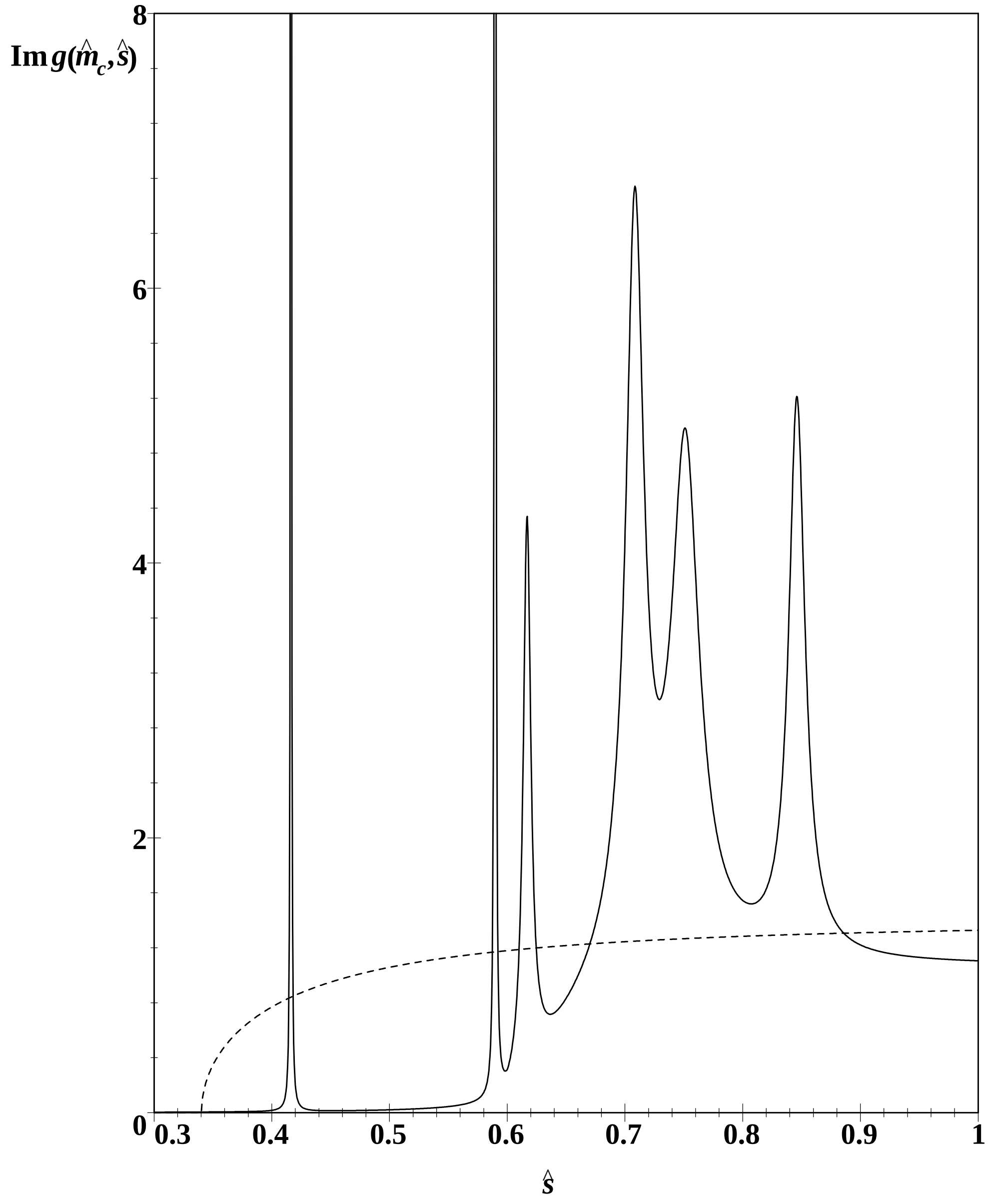

FIG. 1:

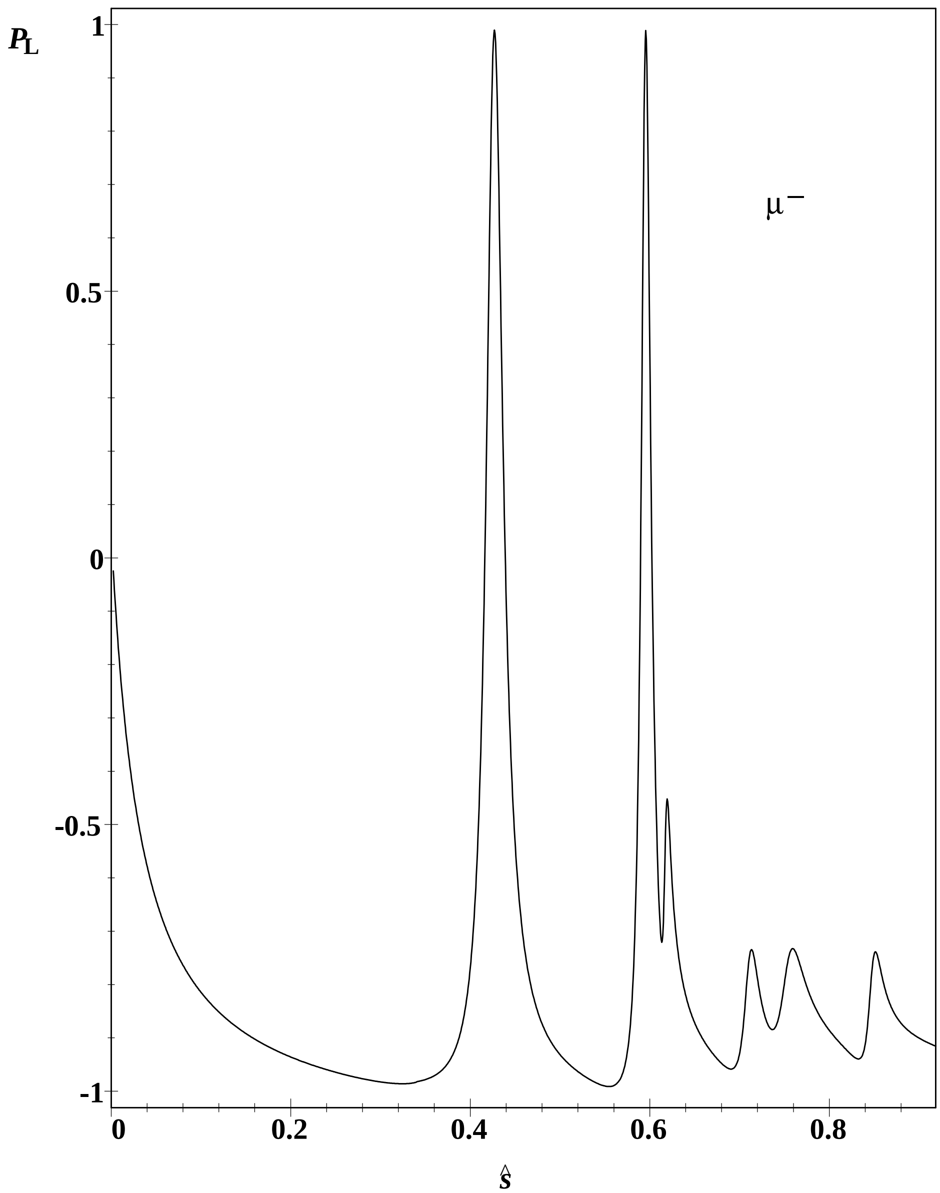

FIG. 2:

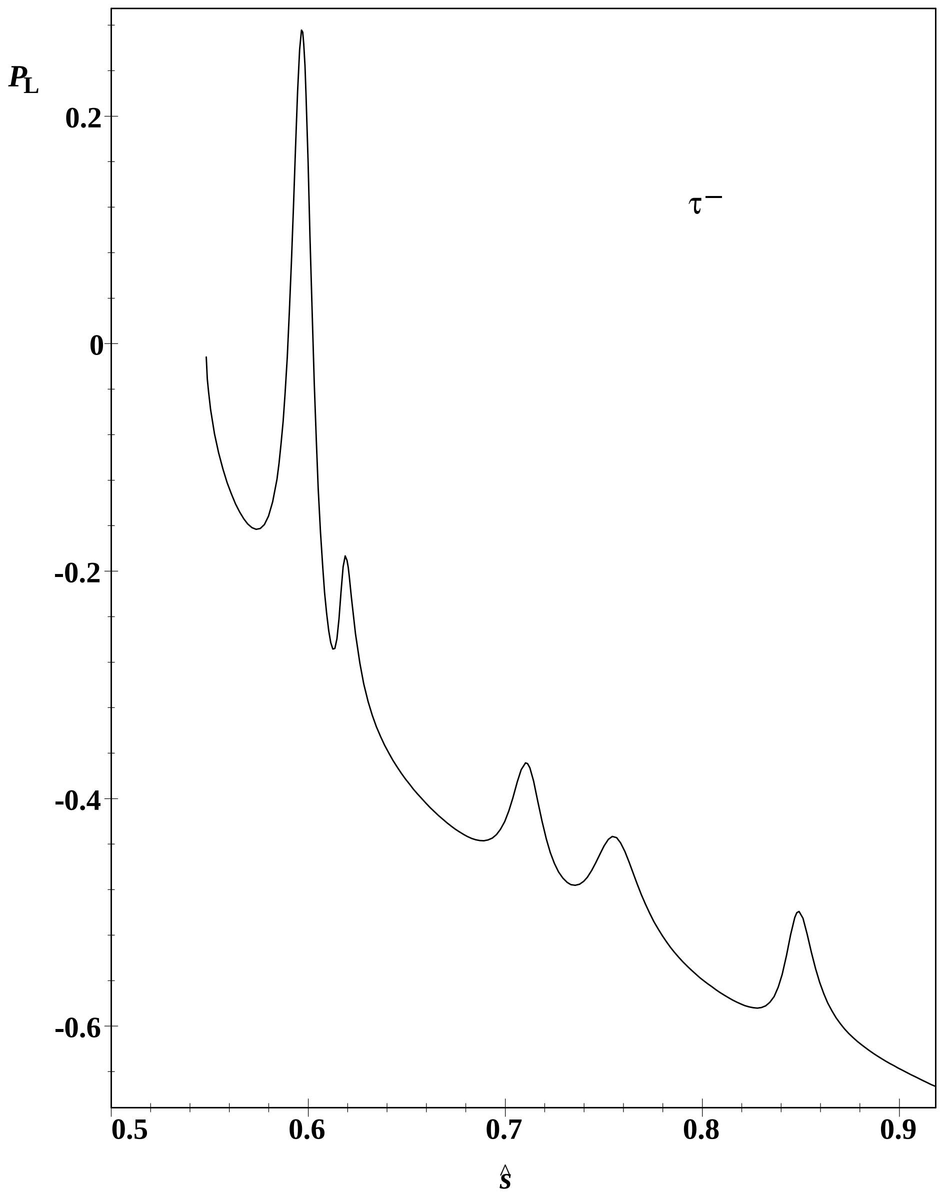

FIG. 3:

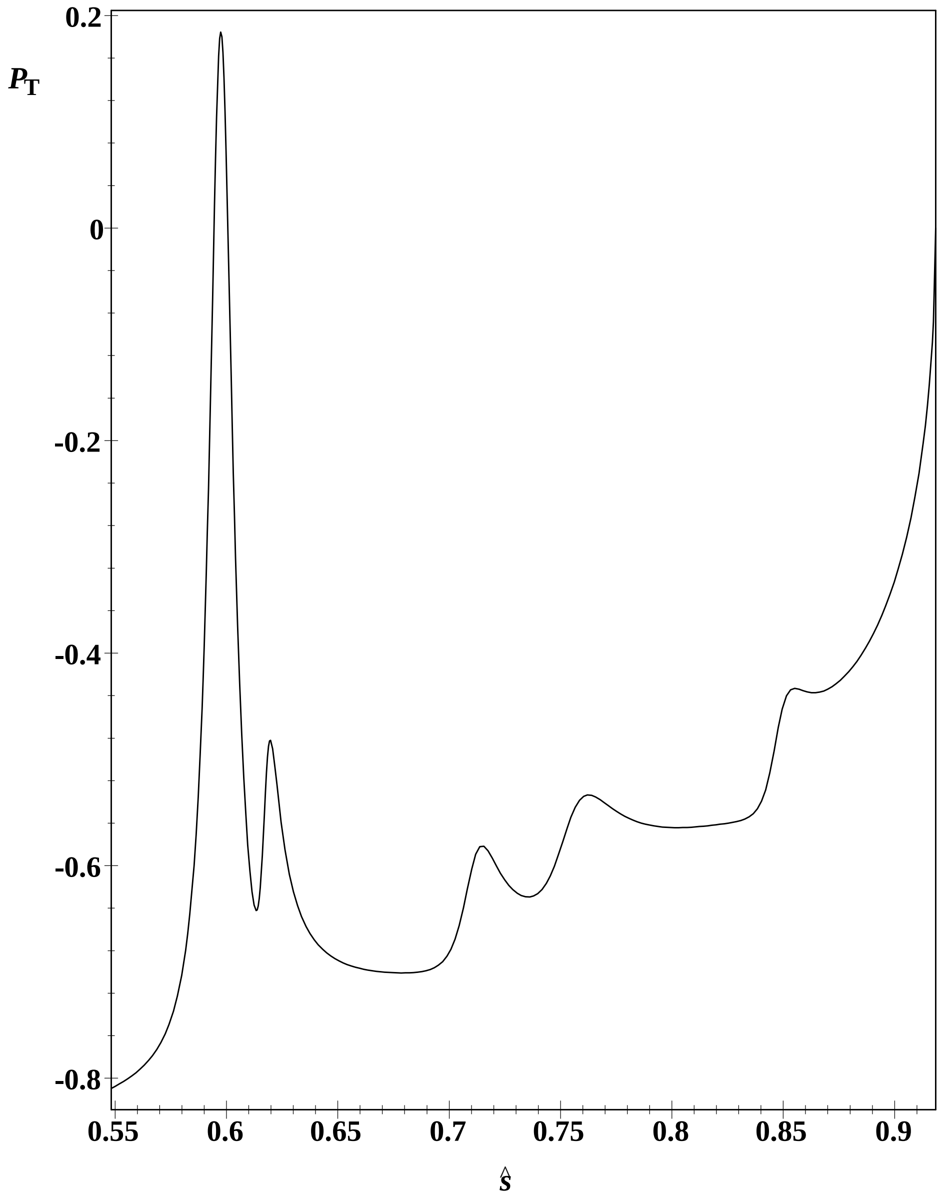

FIG. 4:

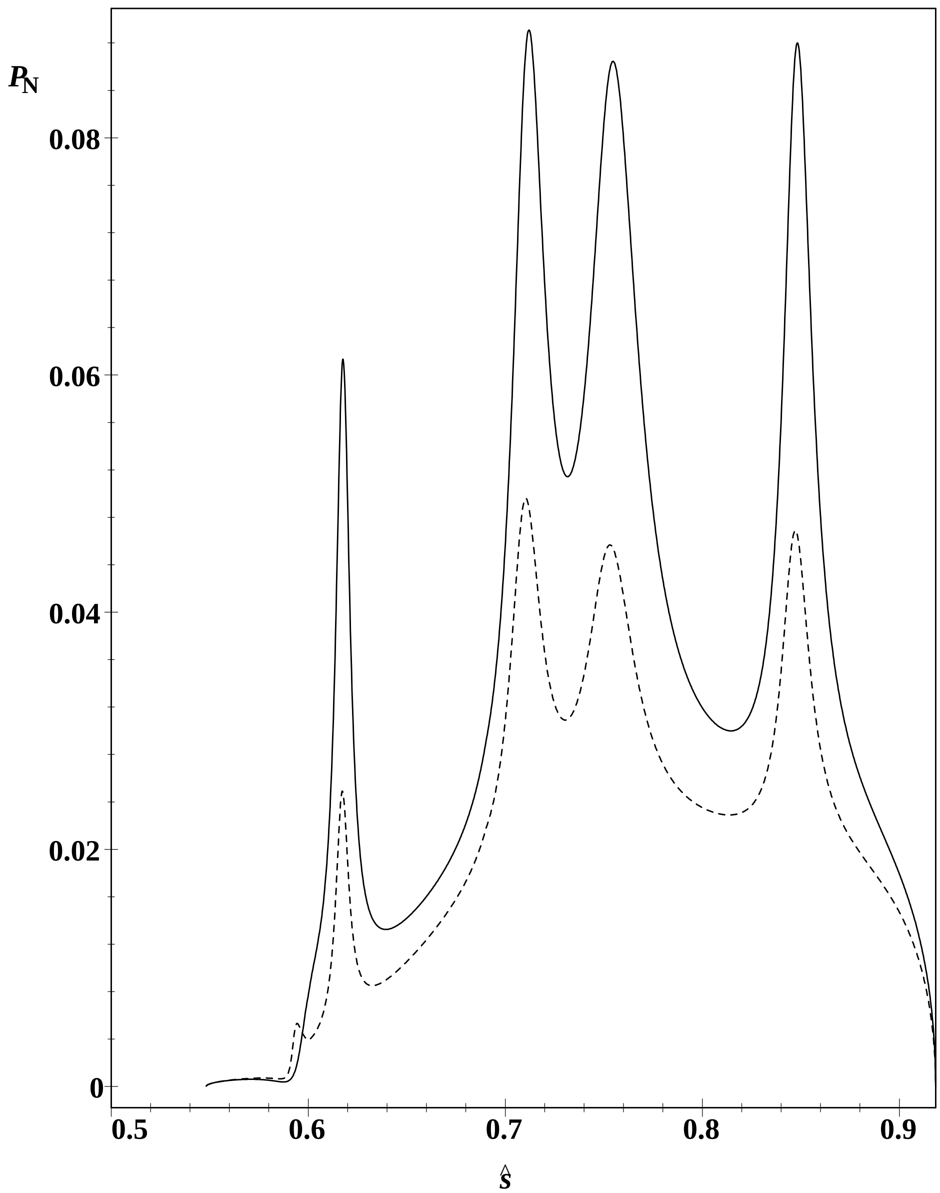

FIG. 5: